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FARM WATER MANAGEMENT IN UPLAND AREAS OF BALUCHISTAN

By W. D. Kemper, Mazher-ul-Haq and Ahmad Saeed

Water Management Research Project
Colorado State University
Fort Collins, Colorado

August 1979

WATER MANAGEMENT
TECHNICAL REPORT NO. 51

FARM WATER MANAGEMENT IN UPLAND AREAS OF BALUCHISTAN

Water Management Technical Report No. 51

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by the Agriculture Department
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Prepared by

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by
W. D. Kemper, Mazher-ul-Haq and Ahmad Saeed

ABSTRACT

Water losses during delivery from source to the field averaged 24%, which is about half as much loss as in the Punjab. Reduced delivery loss was caused by watercourses being shorter (averaging about 3000 ft. from source to field) and having operating water surface levels that are commonly lower than the surface of adjacent lands. Higher cost of water (ranging from Rs. 75 to Rs. 1200 per acre-foot depending on the area and crops grown) also causes most of the farmers to take better care of their water.

Value of water also varied with the season, ranging from zero during January and February when some farmers allow karez water to run to the rivers to over Rs. 1000/acre-foot in the months of May through August when some of these same farmers are buying water from well owners at a cost of over Rs. 1000/acre-foot.

There is a need for storage to save this water from seasons when its value is low to seasons when its value is high. Surface storage such as was built for Zandra Karez behind Sharon bund is considered by the farmers as highly beneficial.

Underground storage and a solution to the high costs of karez maintenance by installing a valved concrete pipe, perforated and gravel-packed in the intake portions of the karez,

appears to be a promising possibility that should be investigated with farmers who see the need.

Overirrigation occurs in the average fields by almost 100%. In karez areas this is caused by lack of farmer control of the rate of delivery water. He wastes the water by over-irrigation rather than letting it go to more obvious waste. Well owners waste water because (1) they do not know how much is enough, (2) electric powered wells are on fixed rates per month and the well owners see the extra water as having zero cost.

Water management problems of these farmers are many, varied and worth solving. A diagnostic approach is suggested with technicians trained to work with farmers and groups of farmers to identify and develop solutions to their problems. This would require a more flexible development program than the Punjab On-Farm Water Management Program. Decisions as to which improvements will be implemented should be based on economic analyses, with improvements initiated only when anticipated benefits exceed costs.

Substantial farmers' inputs should be obtained on all improvements to assure their feeling of responsibility and build their pride of ownership and accomplishment.

Assisting karez shareholders to buy pumpsets for wells to complement their karez water during prolonged drought periods, or as the water table is lowered by surrounding wells should be considered, along with immediate implementation of the May 1978 groundwater ordinance, to protect the rights of groundwater users and prevent economic losses and social disruption that will result from resource dislocation and groundwater depletion.

The volume of runoff water is estimated to be ten times the volume of water retrievable from the ground per year. Farmers attempt to use this runoff water with sailaba type cultivation which involves holding flood waters with bunds until they have entered the soil. Over 90% of the bunds observed were breached due to lack of engineering and provision for overflow. Water trapped in the remaining bunds is not used effectively because the land is not levelled. Bunds are much higher than needed, but are not properly packed. Guidelines for constructing such systems are needed to help these sailaba bunds return more benefits than their costs. Practical research with farmers is needed to gain information on frequency and intensity of runoff events, effective low cost designs for bunds and overflow structures and on the amounts of water that should be retained and types of crops and cultural practices which will use that water most effectively.

FARM WATER MANAGEMENT IN UPLAND AREAS OF BALUCHISTAN[1]

by
W. D. Kemper, Mazher-ul-Haq and Ahmad Saeed[2]

I. Introduction

This brief study was designed to observe, and to some extent, evaluate, the water management practices of farmers in this part of Pakistan. The objectives were to identify specific development activities in the farm water management area which appear to be good investments for farmers and for the Government. In cases where certain development activities appear to have potential for being good investments, but there are uncertainties and alternative methods which should be considered, development oriented research is suggested.

II. Prerequisites for Economically Productive and Permanent Irrigation Agriculture

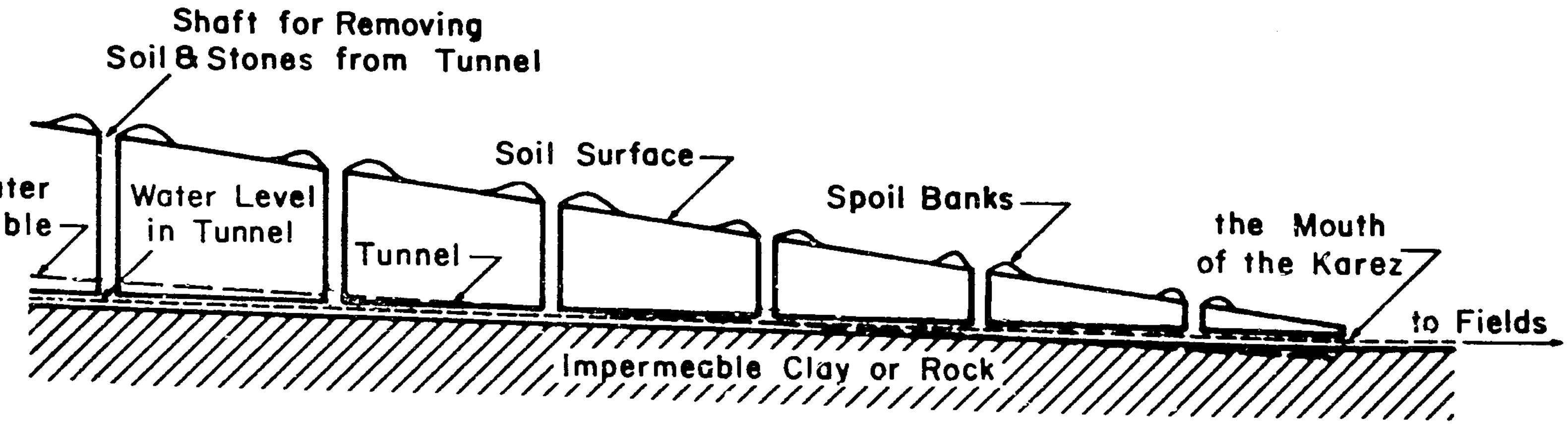
The high elevations (3,000 to 7,000 ft. above sea level), dry weather and the well drained soils provide conditions for good production of high quality apples, apricots, peaches, almonds, grapes, pistachios, pomegranates and other high value crops which have ready markets in the Punjab and Sind Provinces and particularly in Karachi and through this seaport to other nations of the world. A reasonably good transportation

1/Joint preparation by the Agriculture Department of the Province of Baluchistan and Colorado State University. Portions of this work were supported by the U.S. Agency for International Development Contract AID/ta-C-1411.

2/Professor, Department of Agricultural and Chemical Engineering, Colorado State University, Agricultural Officer, and Research and Agriculture Officer Extension in the Agriculture Department of Baluchistan, respectively.

network allows fertilizers and fuel to come in and produce to leave this area. The primary limiting factor is water since the average rainfall is only about 8 inches. This shortage of rainfall has left much of this area as barren rock mountains at the foot of which are talus and gravel which absorb much of the runoff from the mountains and transmit this water to underground aquifers. Over the eons of time these waters filled the aquifers to the point where they rose and met the soil surface at many points as bubbling clear springs. In other areas erosion channels cut down through the alluvium to the water table and this groundwater provided the base flow for perennial streams.

Nomadic tribes found these springs and perennial streams and often made them their headquarters. They began using the excess waters to irrigate a few crops. As their tribes grew, more food was needed and more labor was available to develop their water supply. In some cases more water was obtained from the springs by following the flowing water back into the hills with excavations. These excavated channels were usually based on compacted clay or stone (Fig 1). Sides and roofs of the channels were of slightly consolidated alluvium ranging from silt to boulders in size. These channels eventually extended for from a few furlongs to miles up the valleys and into the alluvial fans of the mountains. Openings from twenty to a hundred yards apart were dug down from the soil surface and used to remove materials excavated from the channel. Erosion caused by rain water entering these openings, earthquakes



Water seeps into the tunnel below the water surfaces and through seepage faces of the tunnel, flows through the tunnel by gravity and is used to irrigate fields lying at lower elevations.

Figure 1. Basic components of a karez.

and other natural factors drop boulders and sediment in these channels which have to be cleaned out with great labor (Fig 2). For these tribes who were willing to cooperate and labor there was a rich reward of crystal clear water flowing to their doors and their thirsty crops. For centuries the water needs of agriculture in this area were provided primarily by these karezes and springs. A steady state was reached utilizing this water which could be brought to the surface of the land by gravity flow. Hand dug wells were used for culinary and stock water, and in a few cases Persian lifts were installed which allowed a camel or a pair of bullocks to lift enough water to irrigate a few acres of precious crop. However, sufficient power was not available to bring significant amounts of this great unused quantity of water to the surface to grow crops of value to man.

Only certain bushes adapted to the desert were able to survive long enough to push their roots down twenty or thirty or more feet to the capillary fringe of the water table. Then if the water table receded, these roots followed. In dry years these bushes and the natural hydraulic gradients which move water to lower areas would draw on the water which they shared with the karezes and lower the water table. If the dry weather persisted for several years the flow from the spring or karez would often diminish, or occasionally stop completely, leading to hunger or migration of the tribe.

Soon after the birth of Pakistan, power in the form of electricity and diesel fuel became available and the

A. Looking into the mouth of a Karez.

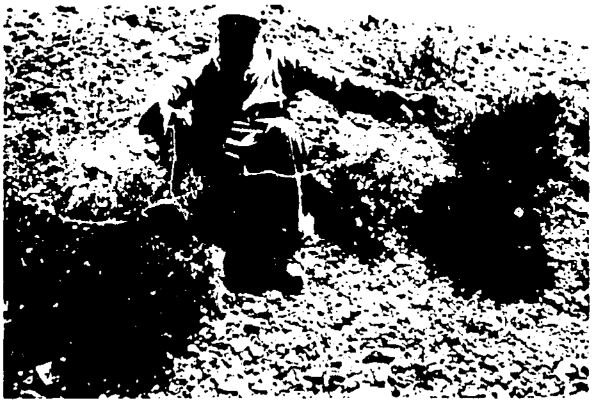
B. Inside the mouth, looking out.

C

D

Figure 2. Karezes and their inhabitants.

The cleaning operation involves cleaners in the tunnel (not shown) who fill bags with rocks and mud and lifters on the surface who pull the bags up through the shafts to the surface and dump them, adding to the spoil bank around the shaft.



E. Desert plants growing on the soil surface.

F. Roots of these plants protruding from wall of the karez, 40 feet below the soil surface.

Figure 2. Karezes and their inhabitants. (Cont'd.)

enterprising and wealthy began harnessing this power to lift water out of wells and irrigate their lands. If a series of dry years lowered the water table they simply excavated down below the water table, lowered their pump, added another length of pipe and began pumping again. Their water supply was no longer dependent on the vagaries of the weather. They could invest confidently in new orchards, knowing that when the trees came of bearing age, they would have water to allow them to produce abundantly.

However these wells which are serving their owners so well, are often thirstily sucking water away from karezes that are nearby. In many cases there are a hundred or more farmers, whose ancestors have farmed their little plots for centuries, who depend on a single karez. To maintain their families on their limited acreages, these farmers have commonly invested in high value crops such as orchards. Suddenly their water supply which has often fluctuated, but for centuries has always recovered, begins to decrease to three-fourths, then one-half, then one-fourth of its former value. Their trees may stay alive on this amount of water, but they cannot bear fruit crops. The only additional water available is that coming from the wells; sucked away from their ancestral karez and now available to them only at a premium price to be paid to the well owner. The karez owner feels that it is grossly unjust to have to pay as much as Rs.1,000 per acre-foot to get back the water that was his own, and especially to make the man rich who took the water from him. But there is often no

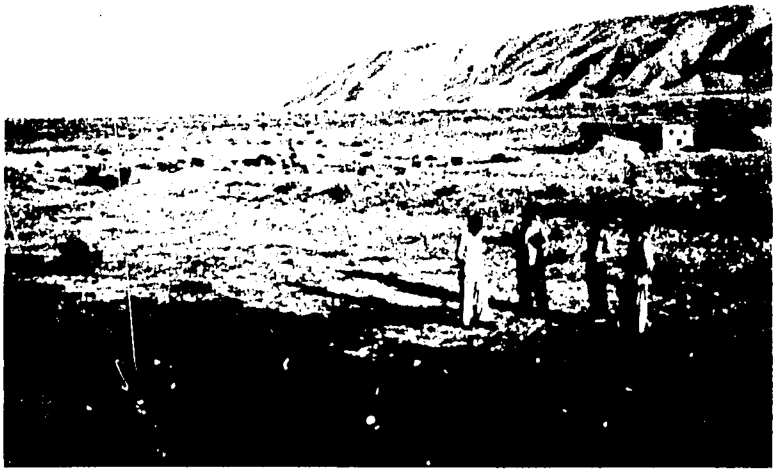


Figure 3. Runoff from barren mountains feeds the groundwater.

Figure 4. Wells with pumps and karezes compete for this groundwater.

alternative if the karez shareholder is to stay in business as a fruit producer. Moreover, while he must be able to buy the well water to stay in business, the well owner is gaining extra capital, looking for new investments, and finds a few karez shareholders who feel their economic positions are untenable and consequently are willing to sell their land. On this newly acquired land the well owner often finds opportunity to use all his water. He also finds that its real value in orchard agriculture is even greater than the Rs.1,000 which he is charging the karez shareholder. Untimately, since there is usually more land than water, economic factors will bring the land resources under the control of the owners of the water. This means economic disaster to the karez shareholder and often forces him and his family to leave the tribal area and seek employment elsewhere. They have lost their share in the permanency of this agriculture.

This might be viewed dispassionately from a national point of view as a shifting of resources to those who have more foresight and capital. A major question that should be answered is whether the well owners, who have large tracts of land, are using their land and water resources as effectively in crop production as the karez shareholders whom they are displacing.

The well owner is often one of the tribal leaders who feel some responsibility for their fellow tribal members. There is the possibility that some of them may achieve the most economically productive of all social systems, the

Figure 5. Measuring flow rates near the water source and near the farmer's fields using submerged orifices.

Figure 6. Measuring water flowing from a well into a storage pond using a Sparling meter.

benevolent dictatorship. What is actually happening in this respect should be determined. This must be done carefully because tribal authority is still strong in many of the rural areas.

Even if shifts in resource ownership are not counter to the social objectives of government they generally incur a degree of economic loss as some of these resources are separated from the other resources necessary to complete the production system. For instance the karez shareholder may hold on to his land until his valuable trees are dead from drouth and the well owner has acquired less suitable but adequate substitutes for this land.

Perhaps the most important question from a provincial or national planner's point of view is "which of these ownership patterns is most likely to achieve a stable, productive and economically viable agriculture?" Accumulation of resources and capital in the land of far sighted and ambitious individuals often leads to rapid private development of those resources into productive systems. It is often only the successful entrepreneur who has dug wells, seen his water turn a desert into a garden and enjoyed the profits therefrom, who has the vision, courage and capital necessary to invest in the distant barren and isolated valleys. The current UNDP study is mapping out those areas in which groundwater is available and these excellent reports provide virtual "treasure maps" for investors who wish to gain ownership of the water in these largely undeveloped but potentially highly productive areas.

If the current high prices for apples, almonds, apricots, pistachios and several vegetable crops remain reasonably stable, this water will become an increasingly obvious good investment. Overdevelopment of the groundwater resource, such as is occurring in the Quetta and Kuchlak areas, could occur. The consequent decline of the water table requires more energy for pumping the remaining water. If controls are not imposed this overdevelopment will lead to the time when the stored water is exhausted. Then the aquifer will no longer serve as a reservoir to avoid the damage and disruption of dry periods. Even if the total supply is not exhausted the costs of pumping the water from great depths are exhorbitant.

To face this situation in the presently overdeveloped areas and to forestall overdevelopment in the other areas of the province the "Baluchistan Ground Water Rights Administration Ordinance, 1978" was issued by the Governor of Baluchistan on 21st March, 1978. Its purpose is "to provide for the management of Ground Water Rights in Baluchistan." Basically this ordinance provides for:

1. A Provincial Water Board: "To administer ground water rights and lay down policies for conservation and development of ground water resources.
2. District Water Committees: To carry out the policies and rules of the Provincial Water Boards, register existing water sources, hold hearings on all applications for new wells and issue well construction permits when applications are approved.

As of September, 1978, the Provincial Board and District Committees have not been constituted. The ordinance, if carried out, will provide basic information to help adjudicate future disputes between users in overdeveloped areas.

Meanwhile, the mapping, quantification of existing groundwaters and their flow and recharge is underway in the UNDP project.

The rules and policies to be formulated by the Provincial Water Board and their administration by the District Committees can bring about a confidence of ownership and avoid depletion of these vital resources. These conditions will provide a strong incentive for the private sector to invest in developing the water resources and productive capacity of the area's agriculture.

III. Functioning of Water Management Systems

A. Procedures

The data outlined in Table 1[3] were obtained by going to the water source and measuring the discharge as near as possible to the pump, spring or karez mouth. Flow rate was measured again, where possible, near where the water entered the farmers' fields.

The person irrigating the field was asked how often and for how long he received the water, what crops were grown and how many acres of each were irrigated in the rabi and kharif seasons. If the irrigator was not the owner, the owner was usually contacted to verify the answers given by the irrigator.

3/These data are abstracted from Appendix II. Water management on specific farms or water supply systems.

Table 1. Water supply rates, watercourse loss rates on application rates.

Study No.	Location / Source of water	Supply source cusecs	Rate field cusecs	Channel length feet	Water loss cusecs	Water loss rate %/1000	Area irrgtd. Rabi acres	Area irrgtd. Kharif acres	Water applied to area irrgtd. Rabi acre-in.	Water applied to area irrgtd. Kharif acre-in.	Water applied/acre Rabi acre in.	Water applied/acre Kharif acre in.
1.	Quetta-Sariab: Dug wells of Niaz Muhammad	0.50	0.34	10,000	0.16	3.2	20	20	1326	1224	66	61
2.	Kuchlak: Dug well of Abdul Baqi & adjacent sources	1.37	1.08	3,500	0.29	6.0	50	30	1733	1800	35	60
3.	Kuchlak: Karez Kona Nasir	0.68	0.63	6,000	0.05	1.2	2	2	16	76	8	38
4.	Pishin-Kuchlak: Dug well of Haji Muhammad Jassan	0.36	0.35	320	0.01	8.7	15.5	11	792	792	51	72
5.	Pishin-Lake: Dug well of Haji Abdul Razzag	0.33	0.23	4,450	0.10	6.7						
6.	Pishin-Lake: Dug well of Haji Muhammad Shah	0.51	0.44	Leaking pond	0.07		25	15	1050	1580	42	112
7.	Bala Neganda near Pishin: Dug well owned by B. N. Villagers	0.70	0.62	4,730	0.08	2.4	1	1	15	45	15	45
8.	Jehangir Village near Killa Saif Ullah: Dug well of Mr. Ramazan	0.46	0.29	1,900	0.17	20.0	21	28	446	840	21	30
9.	Loralai: Karez Ureagde	5	5	short			37	22	1680	1[illegible]90	45	76
10.	Loralai: Karez Rodeleen		1.78				30	13	974	975	3[illegible]	75
11.	Loralai: Karez Matwarkh	1.34	1.07	7,750	0.27	2.6	400	400	5292	5292	13	13
12.	Sinjawi: Karez Passrd	0.91	0.59	7,922	0.32	4.4	7	22	525	525	24	75
13.	Sinjawi: Karez Chilize Mirajikh	2.29	1.55	7,400	0.74	4.4						
14.	Sinjawi: Rehman Karez (adjacent to No. 13)	1 to 6	3*	4,000*	0.70*	4.0*	43	33	4536	4536	105	137
15.	Zandra in Ziarat Division: Karez Zandra	3.1	1.2	10,000	2.00**	N/A	44	34	350	1400	8	41
16.	Ahmadoon Village, north of Junga Bundat: Ahmadoon Spring	1.95	1.84	8,270	0.11	0.7	3	3	32	66	11	22
17.	Giddar Extension Farm: Dug wells and pacca holding tanks	0.64	0.53	2,000	0.11	8.6		40		1845		46
18.	Wad: Tubewell of Mir Sher Jan Mengal	0.62				13.4+	10	7	420	456	42	60
19.	Wad: Tubewell of Mir Rasool Rakhsh Mengal	0.43	.2to.42	1,000			25	21	624	624	25	30
20.	Wad: Tubewell of Haji Gholam Nabi Mengal	0.65					60	16	1404	480	23	30
21.	Wad: Tubewell of Mir Dost Mohammad Lango	0.73					100	20	3024	720	30	36
22.	Turbat: Karez Suragi	0.76	0.68	775	0.08	13.2	5	5	250	291	50	58
23.	Turbat: Karez Mirri	1.25	0.41	2,730	0.84	24.6	6.7	6.7	214	299	32	45
24.	Mastung: Karez Kunger	0.76++	0.61	1,050	0.15	19.2	15	6	210	429	14	72
25.	Mastung: Karez Ishkana	1.20	1.17	1,200	0.03	2.1		4		184		46
	Averages					8.1					33	55.5

*Estimated average.

**This large loss was due primarily to a major break in the pacca channel where it crosses the river bed and has been broken.

+This determination was made using the ponding and recession method.

++This flow was below a holding pond, next to the pacca road and the following 1050 feet was through gravelly soil.

There were many cases where the owners or persons contacted did not know the acreages. In such cases the length and width of the fields were paced to obtain the estimates of the area irrigated by the reported and measured amount of water.

The farmers were also asked to describe any long term or seasonal variations in their water supply. Estimates of the time involved in cleaning the karezes and watercourses were obtained from some farmers. Construction costs and time of construction were requested when well owners could be questioned.

In general the farmers could not recall the details of their irrigation. For instance, they were not able to remember how many hours they spent irrigating their tomatoes as distinct from time spent irrigating lady fingers or other types of vegetables. However they were able to remember the amounts of irrigation time allotted to them per turn and time between turns and this information was used with planting dates, etc., to tell approximately what portion of this water was used on rabi season wheat, orchards, and in a few cases vegetables. On a few farms they were only growing orchards, or during the rabi season they were only growing wheat.

Average flow rate to the fields was estimated from the rate of flow at the source by subtracting the product of the measured loss/1000 ft. times the average distance in thousands of feet to the farmer's fields. This estimated flow rate at the field (cusecs) was multiplied by the number of hours per turn and the number of turns per season to obtain a number which is numerically equal to the acre-inches applied to the area. This number of acre-inches was then divided by the number of acres irrigated to obtain the irrigation application rate to the fields in inches. When bunds were built in orchards to selectively keep water off some of the areas between trees, the whole area of the orchard was considered. This led to some low application rates as indicated at the Ahmadoom spring and Matwarkh karez in Table 1.

Limitations of time at some locations and absence of farmers at others led to several incomplete sets of data. In some of the cases, where delivery efficiencies could not be measured, loss rates observed in adjacent areas were assumed in making the indicated calculations of amounts of water applied to the fields.

Flow rates emitting from wells were measured using a Sparling meter. These flow rates were generally checked a few feet down stream using trapezoidal plates containing circular orifices which were placed at right angles to the direction of flow in the channels. The head loss (ΔH in feet) across these orifice plates is related to the flow rate (Q in cusecs) through the orifice by the equation:

$$Q = 0.65\ A\ (2g\Delta H)^{\frac{1}{2}}$$

where A is the cross section area of the orifice (square feet) and g is the acceleration due to gravity (32.2 feet per second). The coefficient 0.65 was calculated by measuring the flow rate, Q, immediately upstream from the orifice plate using a carefully calibrated Sparling meter and dividing the flow rates by $A(2g\Delta H)^{\frac{1}{2}}$ as measured at the orifice plate.

In some cases the flow from wells is accumulated in holding ponds during the nights and allowed to augment the well discharge to the fields during the day. In these cases the supply rate at the source listed in Table 1 is the rate at which water was leaving the holding tank.

B. Channel Lengths

The channel lengths shown in Figure 1 are the lengths determined by pacing of the channels in which the water was flowing at the time of measurement. In the Loralai and Sinjawi area and at Ahmadoon spring, the water was often divided into two, three or more channels and in these cases the total length of all channels carrying water is included in the figures given in Table 1.

In general the springs and karezes have long channels from the source to the field if they have (or at one time had) large flows which served a large irrigated area. Moreover they do not originate in the middle of the area served but come from the high side of the area and occasionally emerge from the earth a mile or more from the main area which they now irrigate. These factors make the average distance from the sources to the fields surprisingly large. In the case of the dug well of Niaz Muhammad, this long channel essentially replaces two old underground karez channels which dried up as the water table receded. Niaz dug two wells about 1.7 miles up these karezes where there was still some flow, which he directed into these wells. He pumps the water from these wells, including that still coming from the old karezes, into the long channel.

Treating each water filled branch from karezes or springs as a separate channel and eliminating Zandra Karez because of its long concrete lined channel, the average distance from where the karez channel comes to the surface to where the water was entering the fields was about 3,300 feet.

The dug wells of Niaz Muhammad being a rather special case, they were not included in the calculation of an average of 2,800 feet from dug wells to the fields which they were irrigating. This surprisingly large average is due to the fact that wells are dug on the high side of the land to be irrigated rather than in the middle of these lands. Since the well owner often covers new fields of his own which are often not contiguous with his old fields and sells water to users of the old karez system, the average distance of flow from wells was only 500 feet shorter than for the karezes.

At the tubewell of Mir Rasool Baksh Mengal in the Wad area the average distance to the fields was only about 1,000 feet because it was installed in the middle of an unirrigated area where he owned the adjacent cultivatable land. This was also true at the tubewell of Mir Sher Jan Mengal and was to some extent the case at the other newly installed tubewells in that area. This short distance from wells to fields, averaging about 1,500 feet, is generally a result of their being installed in a previously unirrigated area where all the land immediately adjacent to them is served by them and is not because of the inherent differences between tubewells and dug wells. In fact, since discharge of these tubewells averaged about 0.6 cusecs while the average discharge of the dug wells was about 0.4 cusecs one would normally expect that a longer average channel length would be required to deliver the greater tubewell flows to the fields.

C. Loss Rates from Delivery Systems

The average loss rate measured was 8.1% per thousand feet and since the average watercourse length was about 3,000 feet the losses on the way to the average field would be about 24% and the average delivery efficiencies were about 76%.

Where the channels were properly designed and kept clean the losses were greatly reduced. In fact, losses less than 1%/100 feet were observed where the farmers were short on water and were concerned enough to keep their watercourses clean and in good shape as they were at Kona Nasar Karez and at Ahmadoon Spring.

To estimate the costs and benefits of a watercourse improvement program on these watercourses we can eliminate the Rehman and Zandra Karezes and Haji Muhammad Shah's dug well as special cases and conclude that the total loss rate from the other watercourses on which flows were measured is about 3.58 cusecs. The total length of these watercourses which was in use at the time of measurement was about 70,000 feet. Based on observation of the watercourses, differences in losses, between sections of watercourses at the Gidder farm which were cleaned and maintained and those not clean, etc., it appears that the average loss rate of these watercourses could be reduced by 50% of its present value of 3.58 cusecs by a program of designing the channel and its banks to proper dimensions and rebuilding them according to this design. It should be possible to do this and install pacca control structures at junctions on these small watercourses at an average of Rs.2.0/ft. Improving about 210,000 feet of the major channels, on these 16 water delivery systems in this manner should save at least half of the 3.58 cusecs of loss and should cost about Rs.420,000 the first year. Good regular follow up cleaning and maintenance would cost about Rs.0.3/ft. or Rs.63,000/year. Assuming that the water has a value about equal to the lowest diesel pumping cost observed (Rs.354 per acre-foot), the value of the water saved would be 1307 acre-feet X Rs.354/acre-ft. = Rs.462,678. Thus the farmers' benefits in the first year would be approximately equal to the cost. In successive years their benefits would exceed the cost of their cleaning and maintenance program by a factor of about 5.

If the Government provided the structures and engineering and the farmers provided the labor, the farmers' part of the first year investment would only be about Rs.0.5 per foot and that investment could be in the form of off season labor which has a low alternate opportunity cost. Consequently he should be experiencing benefit/cost factors of about 5 from the initiation of the program. In addition to the increased water supply he would have labor savings provided by the pacca control structures. Karez shareholders will probably be eager to participate in such a program. The owners of most karezes are well organized since they have built and maintained their own water supply system, levying assessments and organizing the work. Owners of wells may not be eligible for participation in the watercourse improvement aspect of the "On-Farm

Water Management Project," but they are likely to be some of the most progressive individuals who are most interested in participating in watercourse improvement.

A quick walking survey was generally sufficient to identify areas of probable high loss as indicated by observable leakage, gravel layers, etc. Flow measurement in front of and behind that section confirmed such identification. Remodeling and rebuilding the specific sections could often be accomplished for a few thousand rupees per watercourse and would probably achieve most of the benefit described above. Consequently there is a need for training and equipping water management specialists who would:

1. come to see the farmers when invited to do so;
2. walk the watercourse and take flow and loss measurements with the farmers;
3. help the farmers pinpoint the weakness of their delivery systems and propose specific suitable improvements which would have high benefit/cost ratios.

D. Water Application Rates and Probable Application Efficiencies

1. Distribution in Rabi and Kharif Seasons

The last two columns of Table 1 indicate the acre-inches of water per acre which were applied to irrigated lands during the rabi (November-April) and kharif (May-October) seasons.

In general, irrigation applications were high when the source of water was a newly installed well, as was the case for studies #6 and #18 because the farmers have not yet developed a cropped acreage large enough to use all of their water. They often do not know how much the crop needs. The water is available and so they overirrigate. The overirrigation is likely to be greater when the well is powered by low cost electricity than when it is powered by high cost diesel fuel (e.g. #6 is electric powered, #18 is diesel powered).

Well owners often continue to apply more water than needed even several years after their wells have been installed (e.g. studies #1, 2 and 4). The farmers involved in #1 and 2 both stated that the "water is worth much more than you can sell it for and you are not an intelligent well owner if you sell your water." This concept of an independently high value of water seems to be a factor contributing to their overirrigation of their crops. Even though farmer in study #2 repeatedly stated he should not and would not sell any of his water, a karez shareholder with a small holding nearby told us that he was buying a small amount of water from the well owner in study #2. It is probable that the owner of well #2, who is in the same tribe as this neighbor, felt sorry for the neighbor and is selling this small amount of water "against his better economic judgment" to help his neighbor.

Some of the cases of greatest overapplication of water were by karez shareholders who had planted acreages of crops based on low early spring flows, or low flows during the previous year (studies #14, 12 and 9). They apply the larger present flow with the general notion that more water will increase yield.

Some of the lowest applications were by shareholders in karezes or springs who had limited water supplies (studies #11 and 16) and high value orchards.

The specific techniques which they were using to achieve high application efficiencies will be discussed in the next section.

2. Amounts Applied to Specific Crops

As mentioned earlier, farmers were not able to remember the details of their water distribution among all of their specific crop varieties. However a few of them were growing orchards only, several only grew wheat during the rabi season and a few who had not yet planted orchards were growing only vegetables (tomatoes, potatoes, lady fingers, chillies, melons, etc.) during the kharif season.

To the extent that the application rates on these crops could be sorted out with a reasonable degree of surety, this was done and the data is outlined in Table #2.

Potential evapotranspiration (Etp) for the 1977-78 season was calculated using the modified Penman method and climatic data from the observatory at

Table 2. Water application to crops.

Water source	Location	Water applied (inches) Kharif	Rabi	Total
ORCHARDS				
Karez Kona Nasir	Kuchlak	38	8	46
Dug well of Haji Abdul Baqi	Kuchlak	45	3	48
Dug well of Haji M. Hassan	Pishin	72	55	127
Karez Ureagae	Loralai	76	52	127
Karez Zandara	Zandara Village	41	3	44
Spring Ahmadoon	Ahmadoon Village	22	11	33
Karez Matwarkh	Loralai	13	13	26
	Average			65
WHEAT				
Dug well of Haji M. Hassan	Pishin	-	41	
Dug well of Niaz Muhammad	Sariab	-	9	
Dug well of Haji Muhammad Shah	Pishin	-	42	
Dug well of A.Baqi & other sources	Kuchlak	-	13	
Dug well of Ramazan	Near Killa Saifullah	-	21	
Ureagae Karez	Loralai	-	40	
Rodaleen Karez	Loralai	-	33	
Passra Karez	Sinjawi	-	24	
Tubewell of Haji Ghulam Nabi Mengal	Wad	-	23	
Tubewell of Mir Dost Mohd Longo	Wad	-	30	
	Average			27.6
VEGETABLES				
Dug well of Haji Muhammad Shah	Pishin	112	-	
Karez & dug well of Haji A. Baqi	Kuchlak	75	-	
	Average			94

Quetta. The daily values of Etp, averaged for each week of the respective seasons are given in Tables 3, 4 and 5.

a. Deciduous Fruit and Nut Trees

Most young fruit trees observed had alfalfa as an intercrop for 4 years. Consequently the water requirements of fruit trees with alfalfa intercrop were estimated by using the potential evapotranspiration data (Etp) shown in Table 3 for the respective weekly intervals and multiplying it by the indicated plant coefficients (Kco) to obtain the estimated "actual evapotranspiration" (Actual Et). The "actual transpiration" is tabulated at 7 day intervals for the season.

The plant coefficients, Kco, were estimated from dates of alfalfa emergence and leafing out of trees in the spring and dates of leaf fall and first frosts in the fall. Alfalfa is given a maximum coefficient of 0.8 instead of 1.0 because it is harvested regularly and immediately after harvest, the evapotranspiration is generally reduced to low values. Since the fodder is harvested almost continuously as needed, the average value of 0.8 is used rather than oscillating values. The small fruit trees would add little to the transpiration since their transpiration is compensated for by a reduction in transpiration of the shaded alfalfa.

Table 3. Estimated Et during 1978 for small trees with alfalfa.

Days since planting	Kco	Etp (mm/day	Actual Et (mm/day)	Actual Et (mm/week)	Cumulative Et to date (cm)
0- 7	0.30	2.26	0.68	4.76	0.5
7- 14	0.30	3.02	0.91	6.37	1.1
14-21	0.30	2.41	0.72	5.04	1.6
21-28	0.30	1.63	0.49	3.43	1.9
28-35	0.30	2.76	0.83	5.81	2.5
35-42	0.30	2.48	0.74	5.18	3.0
42-49	0.30	1.73	0.52	3.64	3.4
49-56	0.30	3.18	0.95	6.65	4.0
56-63	0.30	3.18	0.95	6.65	4.7
63-70	0.30	3.81	1.14	7.98	5.5
70-77	0.30	3.64	1.09	7.63	6.3
77-84	0.40	3.97	1.59	11.13	7.4
84-91	0.60	4.22	2.53	17.71	9.2
91-98	0.80	3.73	2.98	20.86	11.2
98-105	0.80	5.84	4.67	32.69	14.5
105-112	0.80	5.90	4.72	33.04	17.8
112-119	0.80	5.38	4.30	30.10	20.8
119-126	0.80	5.17	4.14	28.98	23.7
126-133	0.80	6.39	5.11	35.77	27.3
133-140	0.80	6.55	5.24	36.68	31.0
140-147	0.80	6.43	5.15	36.05	34.6
147-154	0.80	5.96	4.76	33.32	37.9
154-161	0.80	7.31	5.85	40.95	42.0
161-168	0.80	6.19	4.95	34.65	45.5
168-175	0.80	6.18	4.94	34.58	48.9
175-182	0.80	6.61	5.29	37.03	52.6
182-189	0.80	5.03	4.02	28.14	55.4
189-196	0.80	4.44	3.55	24.85	57.9
196-203	0.80	4.89	3.91	27.37	60.7
203-210	0.80	5.09	4.07	28.49	63.5
210-217	0.80	4.27	3.42	23.94	65.9
217-224	0.80	5.17	4.13	28.91	68.8
224-231	0.80	4.07	3.25	22.75	71.1
231-238	0.80	3.96	3.17	22.19	73.3
238-245	0.80	4.02	3.21	22.47	75.5
245-252	0.80	4.08	3.26	22.82	77.8
252-259	0.80	3.26	2.61	18.27	79.6
259-266	0.80	2.96	2.37	16.59	81.3
266-273	0.80	2.68	2.15	15.05	82.8
273-280	0.80	2.84	2.27	15.89	84.4
280-287	0.70	2.41	1.69	11.83	85.6
287-294	0.60	2.19	1.31	9.17	86.5
294-301	0.50	1.73	0.87	6.09	87.1
301-308	0.40	1.66	0.66	4.62	87.6
308-315	0.20	2.69	0.54	3.78	87.9
315-322	0.20	2.32	0.46	3.22	88.3
322-329	0.20	2.21	0.44	3.08	88.6
329-336	0.20	1.87	0.37	2.59	88.8
336-343	0.20	2.06	0.41	2.87	89.1
343-350	0.20	2.25	0.45	3.15	89.5
350-357	0.20	2.35	0.47	3.29	89.8
357-364	0.20	1.60	0.32	2.24	89.9
365	0.20	1.38	0.28	0.3	90.0
Estimated annual water use, 1978					90 cm = 35.5 in.

Beginning date of January 1.

Table 4. Estimated Et during 1978 for mature apples and almond orchards.

Days of year	Etp (mm/day)	Crop coefficients Apple	Crop coefficients Almond	Actual Et (mm/day) Apple	Actual Et (mm/day) Almond	Cumulative Et (cm) Apple	Cumulative Et (cm) Almond
1	2.3	0.3	0.3	0.68	0.68	0.1	0.1
7	3.0	0.3	0.3	0.91	0.91	0.6	0.6
14	2.4	0.3	0.3	0.72	0.72	1.1	1.1
21	1.6	0.3	0.3	0.49	0.49	1.5	1.5
28	2.8	0.3	0.3	0,83	0.83	2.0	2.0
35	2.5	0.3	0.3	0.74	0.74	2.6	2.6
42	1.7	0.3	0.3	0.52	0.52	3.1	3.1
49	3.2	0.3	0.3	0.95	0.95	3.6	3.6
56	3.2	0.3	0.3	0.95	0.95	4.3	4.3
63	3.8	0.3	0.3	1.14	1.14	5.1	5.1
70	3.6	0.3	0.3	1.09	1.09	5.8	5.8
77	4.0	0.4	0.4	1.59	1.59	6.7	6.7
84	4.2	0.6	0.6	2.53	2.53	8.3	8.3
91	3.7	0.9	0.8	2.98	2.98	10.7	10.7
98	5.8	0.9	0.9	5.25	5.25	13.8	13.8
105	5.9	1.0	0.9	5.90	5.21	17.9	17.5
112	5.4	1.0	0.9	5.38	4.84	21.4	20.6
119	5.2	1.0	0.9	5.17	4.66	25.0	23.9
126	6.4	1.0	0.9	6.39	5.75	28.9	27.4
133	6.6	1.0	0.9	6.55	5.90	33.4	31.5
140	6.4	1.0	0.9	6.43	5.79	37.9	35.5
147	6.0	1.0	0.9	5.96	5.36	42.6	39.7
154	7.3	1.0	0.9	7.31	6.58	47.2	43.9
161	6.2	1.0	0.9	6.19	5.57	51.9	48.1
168	6.2	1.0	0.9	6.18	5.56	56.2	51.9
175	6.6	1.0	0.9	6.61	5.95	60.5	55.8
182	5.0	1.0	0.9	5.03	4.52	64.8	59.7
189	4.4	1.0	0.9	4.44	4.00	67.2	61.8
196	4.9	1.0	0.9	4.89	4.40	69.9	64.3
203	5.1	1.0	0.9	5.09	4.58	73.5	67.6
210	4.3	1.0	0.7	4.27	2.99	77.0	70.0
217	5.2	1.0	0.7	5.17	3.62	80.5	72.4
224	4.1	1.0	0.7	4.07	2.85	83.3	74.4
231	4.0	1.0	0.7	3.96	2.77	86.5	76.6
238	4.0	1.0	0.7	4.02	2.81	89.6	78.8
245	4.1	1.0	0.7	4.08	2.86	92.4	80.8
252	3.3	1.0	0.7	3.26	2.29	94.8	82.5
259	3.0	1.0	0.7	2.96	2.07	97.0	84.0
266	2.7	0.8	0.5	2.15	1.34	98.7	85.1
273	2.8	0.6	0.4	1.70	1.14	99.9	85.9
280	2.4	0.4	0.3	0.96	0.72	100.6	86.4
287	2.2	0.3	0.2	0.66	0.44	101.1	86.7
294	1.7	0.2	0.2	0.35	0.35	101.4	87.0
301	1.7	0.2	0.2	0.33	0.33	101.6	87.2
308	2.7	0.2	0.2	0.54	0.54	101.9	87.6
315	2.3	0.2	0.2	0.46	0.46	102.3	87.9
322	2.2	0.2	0.2	0.44	0.44	102.6	88.2
329	1.9	0.2	0.2	0.37	0.37	102.8	88.5
336	2.1	0.2	0.2	0.41	0.41	103.2	88.8
343	2.3	0.2	0.2	0.45	0.45	103.5	89.1
350	2.4	0.2	0.2	0.47	0.47	103.8	89.4
357	1.6	0.2	0.2	0.32	0.32	104.2	89.8
364	1.4	0.2	0.2	0.28	0.28	104.5	90.1
			Annual use:	(centimeters)		104.5	90.1
				(inches)		41	35

Table 5. Estimated Et during 1978 for wheat.

Days since planting	Kco	Etp (mm/day)	Actual Et (mm/day)	Cumulative Et to date (mm)
0	0.10	2.37	0.24	0.2
7	0.14	2.40	0.34	2.7
14	0.18	2.16	0.39	5.7
21	0.22	1.95	0.43	8.7
28	0.26	2.28	0.59	12.5
35	0.30	2.45	0.73	17.2
49	0.30	2.56	0.77	27.7
56	0.30	2.75	0.83	32.4
63	0.30	2.37	0.71	36.8
70	0.30	2.53	0.76	42.2
77	0.30	2.24	0.67	47.0
84	0.30	2.16	0.65	51.5
91	0.30	2.41	0.72	56.6
98	0.35	3.05	1.07	63.6
105	0.40	3.10	1.24	69.5
112	0.50	3.67	1.84	79.7
119	0.60	3.19	1.91	93.7
126	0.70	3.43	2.40	111.1
133	0.80	2.28	1.83	128.9
140	0.90	3.57	3.21	150.7
147	1.00	3.80	3.80	179.1
154	1.00	4.17	4.17	210.1
161	1.00	5.24	5.24	246.5
168	1.00	5.30	5.30	287.3
175	1.00	4.64	4.64	320.9
182	1.00	5.10	5.10	358.3
189	1.00	6.20	6.20	398.9
196	0.90	6.28	5.65	439.5
203	0.70	6.34	4.44	471.2
210	0.50	6.43	3.21	494.4
212	0.20	6.45	1.29	497.0

Beginning date of January 1.

The annual total evapotranspiration for small trees with alfalfa was estimated at 90 cm, or 35 inches. Mature apple orchard was assumed to reach full potential evapotranspiration from mid May through September, as indicated by the Kco values of 1.0 for the weeks from days 133 through 259 in Table 4. Using these values an annual water use of 105cm or 41 inches is computed for mature apple orchard. A mature almond orchard was assumed to reach only 90% of potential evapotranspiration because of its obviously less complete canopy cover and "common knowledge" that almonds use less water than apples. The harvesting process for almonds is commonly to beat them off of the trees with sticks in late July. This also knocks off about 50% of the leaves and damages those that are left. The effect of this defoliation is indicated in Table 4 by an assumption of decreased Kco in August and September. Using these Kco values, an annual water use of 90cm, or 35 inches, is computed for mature almond orchards.

Using these computed annual water use figures as an indication of actual water need, the water application of the farmers indicated in Table 2 are evaluated. At Kona Nasir a total of 46 inches was applied as irrigation water, which is slightly more than the 41 inches needed. However, about

8" of rain were also received during the year for a total of about 54 inches of water received by the orchard. This is an application efficiency of 76%. The farmer was paying Rs.1,000 per acre-foot for well water to supplement his karez water.

At the farm of Mr. Baqi the application of irrigation water was 48 inches per year, which coupled with 8" of rain gave 56" compared to 41" "needed". Both of these orchards in Kuchlak were well tended, but the water was generally one to two inches deeper at the downhill ends of the bunds than at the uphill ends and would contribute to application efficiencies being less than 100%.

Extreme overirrigation was taking place on the orchards of Haji M. Hassan and on the almonds at Karez Ureagae. In both cases the owners have more water than is needed by the land that they are farming, so they overirrigate.

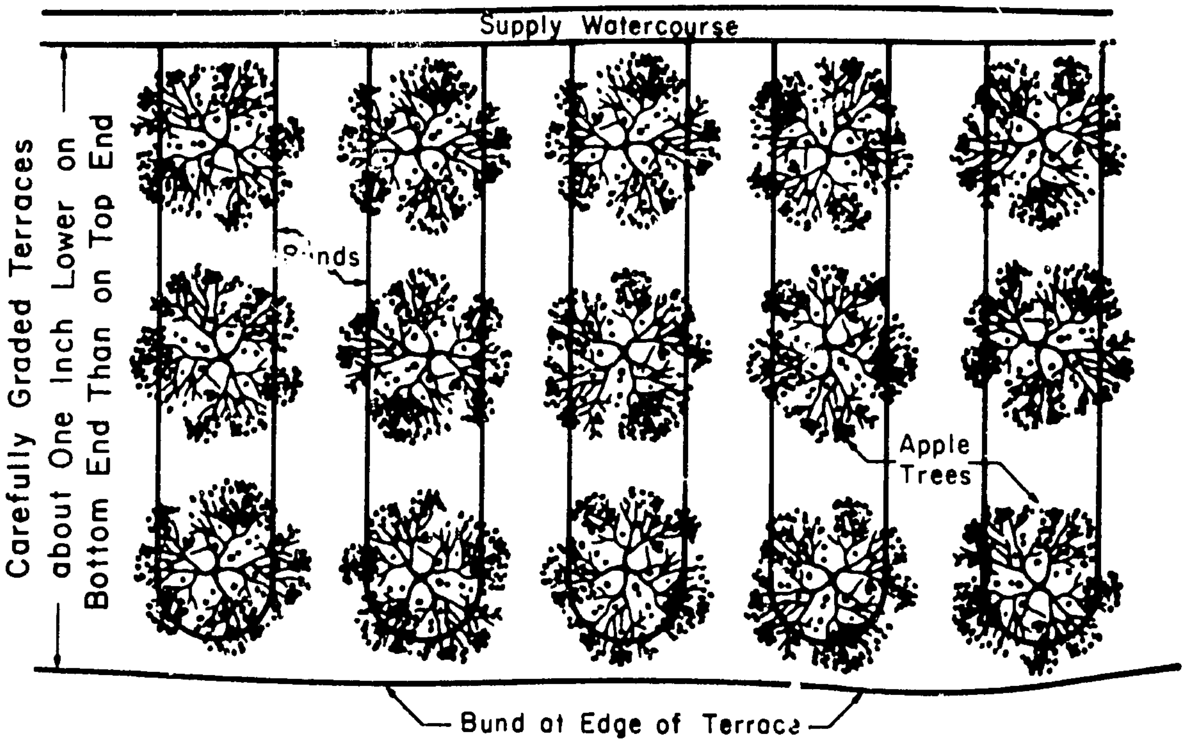
At Karez Zandara the rainfall was about 12 inches and this coupled with 44 inches of water is 56 inches of water received by the apple orchards as compared to 41 inches needed. This allows for a bit of unevenness in the fields and at an application efficiency of 73% gives the plants the amount of water that they need. Apples of the highest quality grown in Pakistan are produced in this village.

At Ahmadoon spring the rainfall was probably about 10 inches which added to the 33 inches of water applied gives 43 inches as compared to 41 inches needed. However, his apple trees were heavily laden with fruit, propped in many places to keep the fruit off the ground. He received this high yield on approximately the computed need by carefully leveling his terraces and bunding them as indicated in Figure 8A. The area inside the bunds and including the trees is irrigated during peak use seasons and area between the bunds is allowed to go dry. When there is water in excess of the plants' need, he irrigates the whole area.

At Matwarkh karez in Loralai the rainfall during the past year was about 10 inches and this added to 26 inches of irrigation gave the almond orchards about 36 inches of water which is about equal to the 35 inches of computed need. The yield of the trees was not estimated since the owners were not available and the almonds had already been picked. However a system of bunds was also used in this karez area. They were of the type indicated in Figure 8B, which encompasses less of the area inside the bunds as compared to those in Figure 8A. The channels between trees are relatively broad at the top, narrowing as

Figure 7. A farmer and his irrigation helper who take water from Ahmadoon Spring and achieve over 90% application efficiency by using the system shown in Figure 8.

A. Used at Ahmadoon Spring in Apple Orchards



B. Used at Matwarkh Karez on Almonds

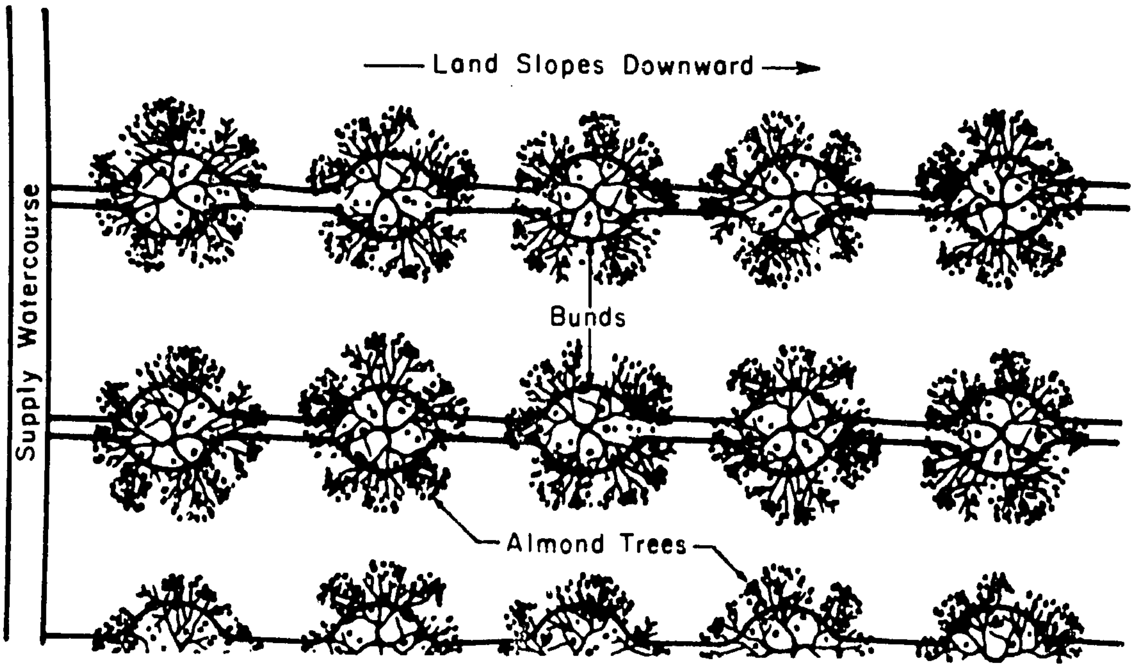


Figure 8. Bunding and irrigation systems used to achieve high application efficiencies.

they are nearer the bottom of the field. The size of the basins however becomes larger as the trees are toward the bottom end of the fields, which apparently compensates for the shorter intake opportunity time. Big trees had larger basins around them than adjacent smaller trees (replacements).

Haji Ghulam Nabi Mengal at Wad has apparently seen this type of irrigation system and had planted his trees in furrows that ran downhill. He was able to provide an irrigation to these young trees using about 0.7 of an acre-inch of water per acre. Apparently, as the trees become larger the furrow is widened around the trees creating a slight basin that appears to be about an inch lower than the general soil surface and is surrounded, except for the inlet and outlet, by a bund of soil about 7 inches high. This system provides the opportunity to control the amount of water delivery to each tree. It seems unlikely that a well engineered trickle system could do much better than these farmers are doing with the system. The end results (water applied only where needed, little land preparation required and water retained during peak use season near the trees where root density and depth is greatest) are strikingly similar. The system used by these careful farmers appears to fit the resources of the country and should be documented with pictures, diagrams and script and made a part of the agricultural extension training. Extension trainees should spend a few days with these farmers learning how to make these bunds and use them to maximize irrigation efficiency in orchards.

b. Wheat

As indicated in Table 2, depth of water applied by irrigation to wheat ranged from 9 inches ("soaking dose" of 5 inches prior to planting and 4 inches of water about mid December), to over 40 inches. This range occurred within a radius of 60 miles where the rainfall during wheat growing season averages about 8 inches. The 9 inch application was by Niaz Muhammad whose watercourse runs through the agricultural research farm at Sariab near Quetta. The technical personnel at the research station have information which leads them to believe that a good wheat crop can be grown on 13 inches of irrigation water and this information may have reached Niaz Muhammad. (If so we should allow him to learn that only about 40 inches of irrigation water are needed for orchards because he appears to be drastically over-irrigating them.) The water needs of wheat are computed in Table 5 and indicate that a total of about 19 inches of water are needed during a November to June wheat growing season.

The temperatures at Wad are higher since it is about 200 miles south of Quetta and is about 1,500 feet lower. Consequently it is probable that wheat will need more water there. However anything over 17 inches of irrigation coupled with rainfall is probably overirrigation for wheat in the Wad area.

Most of these farmers do not apply fertilizer to their wheat. Their yields are down in the 18 to 30 maund range which indicates that urea and ammonium phosphate at the rate of about ½ bag of each per acre, would give them a high benefit/cost ratio and would allow the limited water supplies to grow more wheat.

c. Vegetables

Although most of the farmers are growing some vegetables it is difficult to estimate how much water they were applying. Some said they were watering every 6 days, some were watering every 8 days and most of them were growing the vegetables on beds separated by large (30 inches wide and 12 inches deep) furrows. There is a row on each shoulder of the bed and these rows are generally about 24 inches apart. Irrigation is generally accomplished by filling these large furrows to near their tops and then letting the water infiltrate the surrounding soil. Few if any of the vegetable roots get under the furrow and it is probable that a large part of the water applied in these furrows goes down as deep percolation to the groundwater. This may account partially for the high rates of application noted for vegetables in Table 2. Because vegetables generally have a shorter growing season than alfalfa, and they do not completely cover the ground until late in the season, they generally use less water than the 35 inches computed in Table 5 as alfalfa needs. Consequently it appears that the vegetable growers are overirrigating by a factor of two and probably nearer to three.

There appears to be a need for growing vegetables under alternative irrigation systems such as using smaller, possibly graded, furrows which would offer more opportunity for plant roots to get under the furrows and would allow much smaller applications of water per irrigation. When farmers and researchers were asked why the currently used furrows were so large, the most common answer was that "on unleveled land, large and deep furrows allow distribution of water to high areas of the fields."

IV. Availability in Time of Need of Groundwater Supply

A. Arguments for a Dependable and Controlled Supply

The overirrigation observed in studies 9, 10, 12 and 14 were related to fluctuating water supplies of these karezes.

Karezes often (but not always) skim water off the top most zone of an aquifer and consequently the flows of many of them are highly dependent on small variations of the water table levels at their heads. These farmers in studies 9, 10, 12 and 14 had experienced depressed flows in recent months or years and consequently had planted smaller acreages. More important from an economic standpoint, they had not planted high value orchards to the extent that they could have done if their water supply was constant. Consequently the variability of water supply from their karezes is drastically limiting their economic return from their land and water resources.

On the other hand crop needs for water are not constant throughout the season. For instance many of the farmers do not use their karez water during the winter months and the karezes continue to drain away this valuable resource as indicated in Table 1. The success of the Sharon reservoir which stores water from the Zandra karez (study 15) illustrates the feasibility and economic value of providing karez owners with a storage capacity. Lack of storage capacity is causing more damage than just the loss of the easily identified, unused karez water. Studies 9, 10, 12 and 14 indicate that farmers overirrigate when they have excess water in an attempt to store it in the soil. They far exceed the water-holding capacity of the soil in the crop root zones. They are leaching away a large portion of the nitrate in their soils and would actually increase their production if they let this excess water go directly to the drain, or, preferably, stored it for summer use.

The farmer contacted at Kona Nasir apparently knew or sensed this fact. The fact that he was buying tubewell water at Rs.1,000 per acre-foot during summer months seemed rationally incompatible with the fact that he allows his karez water to go to the drain for over three months during the winter. When asked why he did not use more of his winter water to fill the orchard's root zone during the winter months, he replied that he did fill the soil in the root zone and there was no purpose in trying to give his orchard more water than the soils could hold. Consequently there is a need for a program which would help karez shareholders develop storage for their unused (and misused) karez water so that it can be utilized when needed by their crops. The data in Table 3 show that farmers recognize this need and are interested in building storage even in those cases where they are presently applying all of the water to their land during winter months. In at least some areas (e.g. Kuchlak and Zandra) the value of this stored water to the farmers would be at least Rs.1,000/acre-foot.

B. Surface Storage

Costs of storing this water would be highly dependent on land availability and on topography such as natural depressions, which could reduce the amount of bunds needed. There may be many opportunities to situate the storage reservoirs to collect runoff from a small watershed as was done at Zandra. When this storage reservoir was built it was considered that runoff collection from its small watershed would be a small contributor to the water supply of this reservoir. The farmers report that it has filled from summer rains each year since

Figure 9. Surface storage near Zandra village.

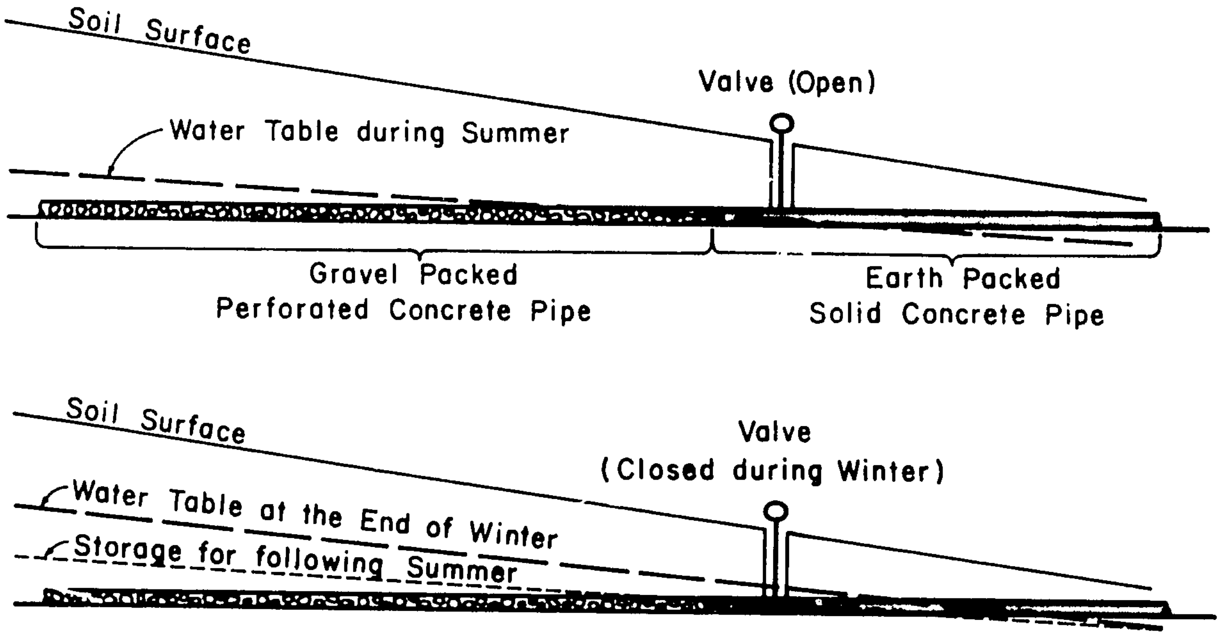


Figure 10. Proposed piping and valving of karezes for underground storage and a permanent solution to karez cleaning problems.

its construction (1973) which has almost doubled the expected supply from this reservoir.

Some sediment comes with the runoff water and the pros and cons of this must be weighed. It could rapidly decrease the holding capacity of the reservoir in some cases of heavy sediment load. On the other hand if the reservoir was built on stony lands, a good coat of sediment that comes in with runoff waters would be helpful in sealing the reservoir to reduce leakage. At Zandra, sediment brought into their reservoir was considered an asset since it was in high demand for "building new soils." After the water level recedes it is hauled away and spread on gravelly areas to build some of the most productive soils in the Province.

C. Underground Storage and a Permanent Solution to the Karez Cleaning Problem

Surface storage appears to be a feasible means for holding excess water for seasons of peak use. However the rates of evaporation and seepage from such reservoirs may decrease their benefit/cost ratio and raise questions as to their economic and physical soundness for storing water during a cycle of wet years to be used several years later during a drought period. The best reservoirs for such long-term storage are often the underground aquifers provided there is not a large hydraulic gradient and high transmissivity in the aquifer which will move underground water away to an area in which it is not usable. The downward seepage and evaporation from these aquifers is considered negligible and since the aquifer already exists there are no high construction costs. Getting the water into the aquifer is generally the problem.

However, karez water is already in the aquifer and keeping it there when it is not needed would appear to be a reasonable approach to saving it for later use. There are high probabilities that a large part of it would flow away to the benefit of other users of the aquifer but there is a high probability that closing the karez when the water is not needed would build up the water table in the vicinity of the karez intake and cause its flows to be greater when it is needed.

However, the flow of most of the karezes observed is never stopped. The main reason given by the shareholders for not stopping the flow is that raising the level of water in the karez loosens the soil, gravel and large stones in the walls and roof of the karez tunnel and causes them to fall into the channel. This necessitates extending cleaning and they are concerned that some of the sections might collapse completely.

Heavy rains are often a mixed blessing to karez shareholders because some of this rain comes down the vertical holes of their karez system directly and loosens considerable material which drops or slides down into the karez channel. Occasionally the carefully made bunds which are built to prevent runoff water from entering these vertical holes are broken and when water runs down these holes a large amount of material is eroded down the hole. The sides of the hole may even collapse, plugging the karez. This causes the water to rise upstream, loosening more side and roof material and the result is a costly cleaning and repair job, or even abandonment of the karez.

With these hazards in mind the high annual cleaning cost (e.g. Karez Sahib Zeda at Kuchlak, Rs.23,400/year; Karez Khawsam at Mastung, Rs.50,000) and the decline in number of people who are willing to do this type of work, a permanent solution to the karez maintenance problem appears to be needed.

One possibility would be to install reinforced concrete pipe in the underground channel. The section of the channel contributing water could be lined with perforated concrete pipe and gravel packed to allow continued entrance of water and to cushion the impact of rocks dropping from the roof of the tunnel. In an intermediate section of the tunnel the area around the pipe could be blocked completely and a valve could be installed on the pipe at one of the vertical shafts to allow closing of the channel when water is not needed. All other vertical holes could be blocked near the surface and covered so that runoff water would no longer enter the channels.

One recent instance of piping a karez was reported in which the inflow had been left open and had filled with rocks. This could be avoided by closing the end of the pipe and allowing the entry of water through an extended length of perforated pipe that is gravel packed.

A shareholder at karez Khawsam showed us the remains of tile which the "old people" had used to pipe part of this karez (about 500 years old). He admitted that he and his fellow shareholders had been unwise when they broke out this ancient pipe and tried to dig the channel deeper. When they did, the walls began to collapse and they have had reduced flow since that time. They would like to have help to place pipe in this portion of their karez so it can function again as the "old people" designed it.

This type of development would essentially prevent the karez owners from lowering the channel of the karez by excavation, which has been done on two of the six karezes studied at tremendous cost in labor. The flows of these karezes have continued to decrease in spite of these efforts. If the unneeded flow had been stopped during nonuse seasons there is a good probability that the water table would have stayed up where the lowering of the channel was not needed.

If adjacent wells are the cause of lowering the water, the water table may continue to decline. However, it is less costly to lower the wells than to lower karezes and the available solutions appear to be: government regulation of well pumping and deepening in the vicinity of karezes; or allowing or encouraging karez shareholders to dig wells, which could supplement their karezes or replace the karez water if the water table drops. If such wells were dug adjacent to the karez and their supply were pumped directly into the pipeline, the major part of normal pumping cost could be avoided because of the small lift required.

Closing a karez against unneeded flow and supplemental wells and pumping to meet dry period needs appears to have sufficient potential benefits that its implementation should be explored with karez shareholders. If they are interested in the potential benefits a karez should be piped in this manner and the response of the water table and karez discharge should be monitored. Since there is a high probability that the benefits of the stored underground water would be shared, at least to some extent, by neighboring down slope wells or karezes it would be justifiable for the government to pay the materials cost of such an installation. However, this type of project should not be done unless the karez shareholders want it badly enough to provide at least the major part of the labor needed. Otherwise they will consider it a government project to be maintained in perpetuity by the government.

Since the water supply is such a vital component of their livelihood, a promise to help them dig and install pumps on one or two wells to replace their water supply if the karez fails might be considered to encourage them to entrust their karez to this type of research.

V. Use of Water in Sailaba Systems (Utilization of Runoff Water for Small Bunded Areas for Crop Production)

Considerable interest in this type of farm water management was expressed by the Baluchistan Departments of Agriculture and Irrigation and by USAID personnel. This is a somewhat different type of water management and time was not available to see the areas where this is done best. Consequently the few observations and recommendations and suggestions for how to get more of the needed information are presented in Appendix III.

VI. Good Investments for Improving Water Management

A. Strength and Scope

During this survey it became apparent that most of Baluchistan's farmers are intelligent, innovative and proud of their ability to solve most of their own problems. A real opportunity exists to capitalize on the collective abilities and pride of these farmers by having technicians work with them to identify their specific potentials for improvement and develop methods for achieving those potentials. The technicians can evaluate the solutions and develop a set of guidelines which can be used by other farmers with similar problems.

Government officials told us that each farmer's system was unique and that solution of their water management problems would not be accomplished by a single homogeneous program. They are correct in this analysis.

In fact, the sailaba system for using runoff water has such unique facets and opportunities for improvement that it is discussed in a separate section (Appendix III). Water management in the lowland areas irrigated by Indus waters and other major canal systems is assumed to have sufficient similarities to that in the Punjab that the Punjab On-Farm Water Management Program will be relevant to the needs.

Even when these important aspects of water management are omitted from discussion, the remaining opportunities for improving farmers' water management are so varied and numerous that most of the following will be suggestions for general diagnoses and specific treatments, rather than for uniform improvement programs.

B. Assisting Farmers to Improve their Delivery and Application Efficiencies

1. Delivery Efficiencies

There are many watercourses in these areas which have little loss, and even in those which have appreciable loss, the leaking portion is often only a small section of the watercourse. Because of relatively large slopes on many sections watercourse dimensions are often such that the normal operating level of the water is near or below that of the surrounding land. This, combined with fine sediments and fewer rodents than in the Punjab make the leakage on many sections of these watercourses less than 3%/ 1000 feet. Under such conditions pacca lining is not recommended. Even earthen improvements of the type used in the Punjab On-Farm Water Management Program are not needed along the whole length of the watercourse, but may be needed on a few specific sections.

The smaller streams make the water easier to control and cross than is generally the case in the Punjab and consequently the general need for pacca control structures and culverts is also reduced. However there are certain sections where the soils are sandy or gravelly where large losses of water are occurring through the bunds. Pacca control structures are needed in those sections.

Pacca lining has been installed extensively and successfully within the province by the Irrigation Department and other agencies to prevent water losses in gravelly and sandy areas. However the high cost of concrete and extremely low loss rates observed in many earthen channels indicate that earth linings could eliminate most of the observed loss at a small fraction of the pacca lining cost. Drop structures to decrease channel grades and reduce erosion would be essential in earth-lined channels.

It is proposed that each program to help a farmer, or group of farmers, to increase the delivery efficiency of their distribution system be preceded by:

a. Inspection of all sections of the watercourse to be considered for improvement.

b. Measurement of loss on all holding tanks or watercourse sections that are suspected of losing water (The inflow-outflow method when the watercourse is in use, is suitable when the sections are long. When sections are short the ponding and recession method should be used. The water levels at which the recession rate is evaluated must include the operating level);

c. Measurement of losses at watercourse junctions and extent of borrow pits;

d. Determination of the time for which water is in the section of the distribution system.

e. Determination of the value of water in the area in terms of its replacement cost (pumping costs, sales, etc.);

f. Decisions on whether to improve specific sections and the types of improvements to be undertaken, based on benefit and cost estimates using the above information and assuming that investment whose benefit/cost ratio exceeds 1.5 should be undertaken.

g. Agreement by all farmers involved to do their share of the work.

2. Application Efficiencies

The broad range of application efficiencies encountered pointed to two major needs. First, the farmers need a water supply which is dependable and can be regulated to fit the needs of their crops. Second the farmers need information as to how much water their crops need and practical advice on how to apply adequate and not excessive water.

One of the primary advantages of wells, compared to canal systems and karezes is that the farmer can store the supply when it is not needed by his crops and thereby have a greater supply when crop needs are maximum. All but a few of the karezes are now operated in an uncontrolled manner with water running to waste, or being used for excessive irrigation during the winter months. Storage of water, either above or below ground, would provide the farmers with much of the needed control.

a. <u>Surface Storage</u>

Success of the Sharon bund, constructed by the Irrigation Department at Zandra, illustrates the value and feasibility of surface storage for providing farmers with the ability to match total water supply to crop needs. Part of the success of that project must be attributed to the additional filling each year from runoff from the small watershed above the "bund", such augmented use of the storage should be considered wherever possible.

If storage is constructed above the command area of the karez, a low lift pump will generally be needed to put water into the storage. However if storage is constructed midway in the command area such pumping can be avoided and extra water can still be obtained by owners of upper portions of the command area by trading their stored water to lower area farmers for direct discharge from the karez.

As a result of decreases in karez flow rates there are surprisingly large acreages of unused land in the middle of many karez command areas, which might be used for water storage.

b. Underground Storage and Maintenance Reduction in Karezes

Surface storage is subject to evaporation and seepage loss. Stopping the karez flow and allowing the water to remain in the ground when it is not needed for crops appears to be a logical means of storage. Most karezes are not stopped because the farmers believe that raising the water level in them may cause loosening of the material in the walls and roofs and will result in more sloughing necessitating more cleaning.

However, many of the karez shareholders contacted are paying from Rs.20,000 to over 50,000 per year to clean their karezes. Karezes could be converted to a water withdrawal system which requires no cleaning by installing concrete pipe in them. This pipe would be perforated and gravel packed in the areas of water pickup near the mother well and would be solid in the other sections of the karez. If the tunnel around the pipe was closed in the central section, a valve on the pipe in that section could stop the water during seasons when it is not needed by crops and allow buildup of the water table which would provide more flow during seasons of heavy need. The fact that the higher water table will benefit neighboring karezes and wells is an argument in favor of government supply of materials for such projects and unaligned decisions by government personnel on pipe sizes which will provide equitable distribution of the water between users.

c. How Much Water is Needed?

Many of the farmers were applying 2 or 3 times as much water as is needed for their crops. Calculations from climatic data and practices of careful farmers who are short of water provide reasonable estimates of the amount of water needed. When the farmers supply rate, duration and frequency of their turns and water holding capacity and root depth of their crops are known it is relatively easy to calculate about how long they should let water run into a field of given area. This determination is particularly simple in Baluchistan during most of the year when the precipitation is practically negligible.

In cases where flow rates may change due to fluctuating levels in storage ponds, etc., measurement structures may be needed and more sophisticated instruction will be needed by the farmer. An alternative would be for the technician to determine how much water is applied per irrigation by the farmer and how efficient that application is and then tell the farmer about how frequently he should irrigate. Many of the farmers indicated ability to adjust schedules or trade turns to achieve such flexibility.

d. Proposals to Improve Application Efficiencies

Storing water from karezes during months when it is not needed so that it can be used in months of peak use is a primary prerequisite for karez shareholders to achieve high application efficiencies. Consequently, helping farmers construct such storage should be a major objective of the On-Farm Water Management Project. The water management teams should be trained in estimating costs of construction of surface storage concrete pipelines, etc., value of water, etc.

Decisions to participate with farmers in such construction should be preceded by:

(1) Evaluation of the need for water during peak use seasons and the cost of alternative sources.

(2) Amount of water that is available for storage and possibilities for gaining an additional filling of surface storage from summer runoff.

(3) Sites available and cost of the sites and construction.

Individuals should be trained at the University of Faisalabad On-Farm Water Management Training Course in how to help the farmer apply the proper amount in the optimum manner. A short term (6 weeks) training course in water management has been proposed for general extension personnel and this type of training would be a good investment if it could be followed by a week of field training in Baluchistan.

C. Advice for Farmers in Newly Irrigated Areas

Groundwater studies indicate substantial amounts of additional water that could be used for irrigation in many areas of Baluchistan. Because selling of land is regarded as social degradation, ownership is more static than in other parts of the world. Consequently the new irrigation farmer is likely to be a local person, not trained in irrigated agriculture.

To service the needs of such farmers and help them make the best use of their share of the country's resources an advisory service should be established which would be available on request to help him:

1. Select the location for digging his well(s);
2. Select a high efficiency motor and pump set which can be maintained under his conditions;
3. Design his fields and distribution system;
4. Plan his cropping sequences and areas;
5. Anticipate the amount of labor and other inputs that will be necessary;
6. Estimate and optimize his costs and benefits;
7. Decide on rates of water application.

D. Research

1. Water Management in Orchards

The amount of water needed by orchards is not known precisely. There are some indications from the observations of this survey that farmers are able to obtain good crops and reduce water requirements, to near the consumptive use computed from climate data, by bunding practices which reduce the amount of evaporation from inter tree areas. If these indications are true, knowing the benefits of such practices, and how to institute them are essential to optimizing the water management and orchard production in Baluchistan. A carefully designed study should be developed as soon as possible to evaluate these practices.

Knowing the exact amount of water that needs to be applied to crops to obtain the maximum net economic return is essential to optimizing the use of water in terms of benefits to Baluchistan. A system that could be used to determine optimum amount of water is the "hose pull trickle irrigation system" suggested by Keller and Burt in 1975 while on TDY with the CSU team in Pakistan.

For instance, small delivery lines of 3/16th inch I.D. plastic tubes could deliver water to each tree. The other end of these tubes might attach to a lateral line of plastic tubing about 1.25" I.D., attached in turn to the water supply. The delivery system can be moved every 12 hours or 8 hours and is designed to provide a separate water line to each tree in a setting. Using this type of distribution system it is easy to modify specific delivery tubes and calibrate them so that trees in each setting obtain a specific set of differential irrigations.

For instance, the equivalent of 25, 30, 35 and 40 inches of water per acre per year could be applied to sets of the trees in the Agriculture Department almond grove in Mastung and yields could be measured to determine the optimum rates of water application.

It is proposed that this study and others which are being outlined by Mr. Ismail and Mr. Haq of the Agriculture Research Division and Dr. Bowers of CSU be implemented as soon as possible to obtain the information that these orchard growers need to optimize their water management and crop production.

2. Water Management in Vegetables

More than 50% of the water applied to vegetables in the currently used wide and deep furrows is not being used by the plants. The reason given by some informants for using these large furrows rather than normal size furrows was lack of levelness of the land. Consequently studies are needed as soon as possible to determine whether yields can be maintained while using less water on leveled land with smaller furrows. These and other studies being developed by Ismail, Haq and Bowers should be initiated as soon as funding can be obtained.

3. Pumping Efficiencies and Well Designs

The average overall pumping efficiencies are down around 15% for the pump sets measured by the UNDP groundwater study to date. In some cases large motors, pumps and wells are irrigating areas of less than

6 acres. Well capacities are often the limiting factor. Smaller efficient pump sets are needed to serve the needs of small farmers. A cooperative effort to design and test pump sets for these conditions should be undertaken by either the Irrigation or Agriculture Departments and a commercial pump manufacturer such as KSB.

The standard dug well, 8 or 10 feet in diameter is becoming more costly to dig as labor prices increase. Other alternatives should be evaluated such as the small vertical shafts used on karezes and exploratory wells, going down to below the water table and then following the most highly permeable layer with karez type tunnels (while the water is being pumped out of the well) as far as is necessary to achieve the desired capacity. Such wells should be better adapted to the needs and resources of small farmers. The small diameters would reduce the probabilities of wall collapse. The tunneling techniques are known and are being used in large wells and karezes.

E. Education

The major limiting factor in development and research in on-farm water management and crop production is lack of relevant college level training for Baluchistan's agriculturally oriented population. Despite the agricultural orientation of Baluchistan's economy, there is no agricultural college in the Province. Arrangements have been made to send 35 students per year to Tandojam and 5 students per year to Faisalabad. About 200 students apply each year, and the seats are filled, but only a half dozen or so agricultural graduates return to Baluchistan each year from this program. Reasons given for nonreturn included:

1. Homesickness and dropping out.
2. Depression in these climates and cultures so different from their own and resultant academic failure.
3. Feeling that the agriculture they are learning is not relevant to that at home.
4. Becoming enamoured with the new culture so they do not wish to return to Baluchistan.
5. Better job offers elsewhere than in Baluchistan.

Whether or not these are the exact reasons, Baluchistan is not getting the trained agriculturists that it needs to solve its problems, many of which are distinctly different from those in the Punjab and Sind Provinces. There appears to be a need, and no feasible alternative for developing an Agricultural College in Baluchistan. The best location for initiating such a college appears to be at Quetta in connection with the University.

APPENDIX I

APPROXIMATE COSTS OF PUMPING WATER FROM DUG WELLS IN BALUCHISTAN
(Assuming digging in 1978 and other prices indicated)

Initial Capital Costs (1978)	Electric	Assuming	Diesel
Digging:			
Above water table, Rs.3000/yd	9,000	30 yds	9,000
Below water table, Rs.1000/yd	4,000	4 yds	4,000
BECO Engine & Pump		26 H.P.	75,000
Pipe: 3" Rs.36/ft			
4" Rs.48/ft	7,200	150 ft	7,200
Pulleys, belts, mountings			5,000
Fall box	2,000	6x8x3'	2,000
Electric motor with pump	26,000	26 H.P.	
Transformer, Rs.3000	3,000		
Electric line @ Rs.1000/pole	10,000	10 poles	
Installation costs	5,000		5,000
Initial Capital Costs	Rs.66,000		Rs.107,200

Diesel Powered Systems

Annual Costs

Operating Cost: Fuel & oil Rs.8/hr @ 5000 hrs/year	40,000
Operator-Mechanic	6,000
Maintenance & Repair: Motor, Rs.2000; Well cleaning, Rs.1000	3,000
Depreciation @ 10%/yr on pump, motor, pulleys & pipes	8,700
Interest on capital @ 15%/yr	16,080
Annual Cost	Rs.73,780

Unit Costs for Pumping Water

For output = 0.25 cusecs for 5000 hours = 1,250 acre-inches
Cost = 73,700/1250 = Rs. 59/acre-inch
= Rs.708/acre-foot

For output of 0.50 cusecs. Cost = Rs.29.5/acre-inch = Rs.354/acre-foot

Electric Powered Systems

Annual Costs

Operating Cost: Electricity @* Rs(60+104)/month x 12 months	1,968
Operator	3,600
Depreciation @ 10% on pump, motor, transformer & pipe	3,620
Interest on capital @ 15%	9,900
Maintenance & Repair: Motor Rs.1300/year, well cleaning Rs.1000/yr	2,300
Annual Cost	Rs.21,388

Unit Costs for Pumping Water

For 0.25 cusecs output for 5000 hours = 1250 acre-inches
Cost = 21,388/1250 = Rs.17.1/acre-inch = Rs.205/acre-foot
For 0.50 cusec output for 5000 hours = 2500 acre-inches
Cost = 21,388/2500 = Rs.8.6/acre-inch = Rs.102.6/acre-foot

*Assuming monthly cost of Rs.60 + Rs.4 x horsepower of motor
= Rs. (60+4x 26) = Rs.164/month for a 26 H.P. motor.

APPENDIX II

ESTIMATES OF EVAPOTRANSPIRATION FROM WATERCOURSES AND NONBENEFICIAL EVAPOTRANSPIRATION FROM THE HYDROLOGIC SYSTEM

There are generally two purposes for such estimates. The most obvious is to determine the role of this factor in decreasing the amount of water which reaches the field. Another important question for which hydrologists need answers is: What portion of the losses from watercourses is lost from the system by evapotranspiration, and what portion is returned by deep percolation to the groundwater?

Many watercourses in Baluchistan connecting the source to the cultivated area, run through otherwise dryland which normally only grows a few scattered desert weeds or bushes on the few inches of precipitation received. The distance from these watercourses to which the water wets the soil is clearly visible while the water is running and is visible as a carpet of green grass after the watercourse has been used for a few years. If the water carries an appreciable amount of salt, there is often a white "salt line" at the extremity of the area to which the soil is wetted.

In sandy soils the extent of wetting was observed to extend as far as five feet from the center of the watercourse (four feet from the inner bank) over extensive sections of watercourses. In finer textured soils the wetting distance varies from about two feet from the center (one foot from the inner bank) to four feet from the center, averaging about two feet of wetted area along each bank. Wet soil, or

Figure II-1. Lateral seepage from a watercourse and resulting vegetation and salt line in a sandy soil.

growing grass in this area provides close to maximum evapotranspiration.

When watercourses leak or overtop, the water commonly spreads over the surface of adjacent cropped land and generally does more harm than good. However, if the land has already been adequately irrigated most of the leaked water will go to deep percolation (or actually displace water that is in the root zone which will, with its nitrates, leave the root zone and percolate downward.

Consequently the increased evapotranspiration which should be attributed to a watercourse is largely limited to the area ir the watercourse and a strip extending from one to four feet along each bank.

Since the average distance from source to field of these watercourses was about 3000 ft. the evapotranspiring area that should be attributed to the watercourse in sandy soils would be about 10 x 3000 = 30,000 ft. and the average transpiring area along a watercourse in finer-textured soil would be 6' x 3000 = 18,000 ft. Assuming average potential evapotranspiration to be equal to 7 millimeters of water (=0.023 ft) per day during the irrigation season the potential evapotranspiration losses from watercourses in sandy areas and in fine textured areas would be about 690 and 414 cubic feet/day respectively. This amounts to loss rates of 0.008 cusecs and 0.005 cusecs for the day when the water is in that watercourse. In some sections the water runs continuously so these steady state losses are the average rates of loss. In other sections, the water is moved to different branches and only resides in a branch for a day or so, giving a good irrigation to the adjacent bank and soil which generally keeps the vegetation transpiring until the next time the watercourse is used. Consequently, the average time for which the watercourse provides water for evapotranspiration varies from about 1.0 times its residence time (for continuous flow), to 14 times its residence time (if it flows in the channel for one day out of 14 and the stomates of the vegetation remain open during the daylight hours in the interim). This supply/residence time factor is estimated to average about four for these watercourses (compared to 5 or 6 for Punjab watercourses handling 4 or 5 cusecs which rotate turns weekly).

Consequently, it is estimated that total loss of water due to evapotranspiration on to these 3000 ft watercourses will be equivalent to 0.032 and 0.020 cusecs, respectively in sandy and clay soils, during the time that water is in that section of the watercourse.

However, many farmers are planting willow trees along some sections of their private watercourses. These serve as a source of firewood, as stakes to stake up tomatoes, etc. These willow trees can drastically increase the evapotranspiration fed by the watercourse. Under relatively calm conditions, the height of the trees can be added to the wetted width of the watercourse to estimate the area for evapotranspiration. For trees whose height is twice the wetted width of the watercourse, this raises the steady state evapotranspirational rate by a factor of about 3 and since the supply/residence factor of about 4 is applicable, the amounts of water pumped from the watercourse supply by these trees will be up near an equivalent of 0.10 cubic feet/second under relatively calm wind conditions. If 10 miles per hour breeze is passing hot dry air from adjacent dryland through these trees additional water will be lost, perhaps even doubling the rate. Many farmers are planting these willows around their ponds and the main channels leading from their ponds to the fields with the mistaken concept that the trees will shade the water and reduce evaporation and save water.

These trees also make cleaning and access to the watercourse more difficult and thus further contribute to water losses.

Assuming no trees planted in this manner it is estimated that a 3000 foot watercourse will dissipate 0.02 to 0.03 cusecs of water to evapotranspiration. Most of the other inefficiencies, such as excess irrigation, result in deep percolation of water and recharge to the aquifer. The obvious loss in the deep percolation is the pumping cost. Losses of nitrate and yield may be even more important.

Conclusions

If willow trees were planted along all sections of the watercourse they could increase the evapotranspirational losses by a factor of four or five, so that as much as 20 or 30% of the supply could be dissipated by them in evapotranspiration. Fortunately, less than 10% of the watercourses have had trees planted along them and consequently over 85% of the losses from the irrigation system is probably returning to the aquifer.

The value of the water removed from the irrigation system by willows and other low value trees on pond and ditch banks exceeds their value.

APPENDIX III

USE OF WATER ON SAILABA AND BARANI LANDS

In spite of the low average rainfall in Baluchistan, over 20% of this rainfall is estimated to run off the land and find its way to the Indus, the sea, or salty inland lakes. This runoff water is estimated to total about 10 million acre-feet per year while the groundwater available for irrigation is estimated at about one million acre-feet. Officials in the agriculture and irrigation departments indicated a need for guidelines and information for the farmers in Baluchistan who are trying to grow crops on this runoff water.

Assuming 8 inches of rain per year and 20% runoff, there should be 16 acre-inches of runoff per year from 10 acres of land. If this can be trapped and held on an acre of land until it infiltrates, and if it comes at such intervals that it can be absorbed by the crop root zone, this should, along with incident rainfall, be enough to raise a reasonably good crop of maize. It should be more than enough to raise a crop of wheat.

The major problem is that rainfall is so sporadic that the probability of getting such rain on any given 10 acre area in a given year is only about 50%. Crop failures would occur in the other 50%. To increase the probabilities of having runoff available, the diversion is often made a few miles down stream on these usually dry stream beds. Since they draw from a larger watershed, often several square miles in area, there is a higher probability of rain showers occurring in part of their area and having the water available each year. Of course as diversions are made further downstream the water also becomes harder to manage, often developing into a raging torrent. Despite these hazards, a large portion of the fertile lands of Baluchistan are crisscrossed with bunds designed to trap and hold water so that crop can be grown in this manner. This type of agriculture is encouraged by the Government bulldozer program which makes a bulldozer and operator available to farmers at a rate of about Rs.40/hour, subsidizing the other 3/4 of the bulldozer's real cost from government funds.

Most of these entrapment bunds are made with no technical guidance other than the experience of the bulldozer operator. Overflow spillways are often not arranged for. Earth for the bunds is commonly borrowed from immediately upslope of the bunds, these borrow pits are often not filled and little effort is normally made to level the land (Fig. III-1).

Over 90% of the bunds observed had been breached. When they have a growing crop which will be damaged by prolonged inundation, the farmers will breach these bunds deliberately after water has stood on them for the time needed to obtain reasonable depths of infiltration. However, almost all of the breaches inspected appeared to be accidental.

As a result of these accidental breaches the bunds lost most of the water from the runoff event that breached them and have lost practically all of the water from each subsequent runoff event. At least 50% of them appear to have been abandoned. Where the bunds were or had recently been intact

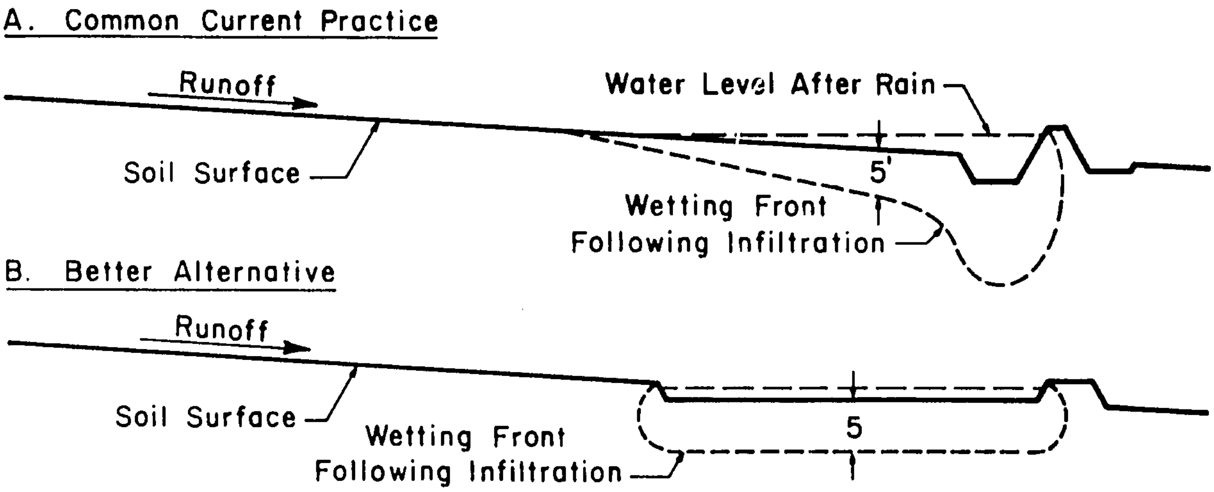


Figure III-1. Land forming for sailaba (runoff → run-on) farming.

Figure III-2. Young fruit trees growing on a well designed sailaba area near Ahmadoon Spring.

maize, sorghum, and melons were the crops grown. In several of these water was standing in the borrow pits, covering drowned maize seedlings while within 50 feet of these borrow pits the maize was suffering from drought. In others, where the borrow pits had been reasonably filled, there still tended to be a low area near the bund with the natural shape of the land leaving a gradation in the amount of water that had infiltered from the water trapped in the basin. Frequently this results in the maize being yellow and nitrogen deficient adjacent to the bund where excess water has leached the nitrate from the root zone, then there was a band 30 to 60 ft wide of green, healthy looking plants. Beyond this the plants had obviously been short of water and were withered.

There is obviously a major investment being made in these "Sailaba" systems, but it appears unlikely that it is generally profitable under the current construction designs and use.

Irrigation Department officials reported that there are some areas where farmers are making this system work fairly well. Unfortunately there was not sufficient time to travel to these areas.

To make these sailaba basins reasonably permanent they should have provision for overflow at a level equal to the amount of water that can be held in the crop root zone. To provide a good environment for crop growth there should also be provision to drain these if water comes when the crop does not need it.

Based on our general knowledge of soil physics and plant soil water relations the following tentative recommendations are made.

Tentative Recommendations

When the crops to be grown are corn and sorghum, their maximum rooting depths in sandy and fine textured soils will be about 5' and 4' respectively. The amount of available water that can be held by these soils is about 0.20 and 0.25 ft of water per foot of soil. Consequently there is not much purpose in having the maximum depth of water in these basins exceed one foot. Bunds to retain this water should be built about 24" high above the level of the flat basin prepared for the crop and should be at least 3 ft wide at their tops and packed as hard as possible to reduce the possibility of rodent holes penetrating through them. An overflow should be built of masonry or concrete, or as a vegetated waterway, which will begin to overtop when the level of water in the basin reaches one foot and is broad enough to carry the maximum expected flow with no more than a 16" of water in the basin leaving 8" of freeboard on the bunds.

Soft, unpacked bunds, are an invitation to rodents which prefer to dig in soft soil. A gate should be provided to let excess water out of these bunds if runoff events follow each other closely and the extra water will do more harm than good. However, if such events are rare the farmer may prefer to breach the bund to allow such drainage after the rain has stopped rather than invest in pacca structures. The main problem with this procedure is that some erosion generally takes place as the water goes through the bund and there will be a general tendency for laborers to put less soil back into the breach than has been removed and to fail to compact it. The results will be a weak point in the bund, which is likely to breach during future storms.

The bunds should be inspected at least once a month during the season when runoff events can be expected. If there are holes indicating rodent activity in the bunds, poison should be placed in the holes for a few days and then moist soil should be pounded into these holes with a belcha (shovel) handle.

The bunded basin should be leveled to within plus or minus one inch. How much area the basin should enclose depends on the amount and frequency of the runoff expected. Local experience coupled with a bit of open channel flow theory is probably the best guide for estimating this. If the farmer or other locals can remember how high, long, and often water has flowed in local nullahs and the average cross section and slope of these nullahs can be measured, a reasonable estimate of the flow rates through these nullahs can be gained. The duration of such events can then be used with these flow rates to estimate the amounts of water per event. If water is to be diverted from these specific nullahs to the sailaba basins the information on expected flows can be used to design sufficient basin area, assuming filling to a depth of one foot, to handle the flow.

Since the flow estimates are somewhat tenuous, it would probably be wise to build only about half the area of basins required to hold the estimated flow, with the other half to be built if observation of performance of the first half indicate that more are needed.

If the inflow level of water to these basins can be controlled so it never rises more than 16" above the level of the basin and the water can drain back out of the inlet to the one foot level when the runoff event is over, separate overflows are not needed.

Another question that must generally be answered is "what is the reliability of such water supplies?" If about 15" of water can be stored in these soils before and during the growing season, there is a high probability of a good crop of wheat. Because maize and sorghum grow during seasons when the potential evapotranspiration is higher, they require about 20" of water to mature a crop.

However, the variability of the rainfall in this area is such that there will be some years when there is not sufficient runoff to raise a crop. Consequently the farmer must have sufficient food or cash reserves, or another source of income to survive such drought periods. Consequently farmers who already have small holdings in the area which are irrigated by groundwater, will be good prospects for farming such sailaba lands. Another possibility is that relatively wealthy land owners may hire tenants to farm their sailaba area paying them a minimum wage which would prevent starvation, plus a share of the crop.

Needed Information and Practical Research

The above recommendations do not make a complete plan for success. The question of whether such a crop production system is economically viable has not been addressed. Data is necessary on the following factors before an economic analysis can be obtained.

1. Cost and durability of pacca overflow structures.
2. Cost of building and compacting sailaba bunds.
3. Cost of land leveling and recurrent costs due to sediment deposition.
4. Other crop production costs.
5. Actual depth of rooting and water extraction patterns.
6. Actual water use rates of various crops under these oasis type conditions.
7. Actual runoff percentages and rates from the contributing watershed as a function of rainfall amounts and intensity.
8. Yield and market price of the crop produced.

Knowing the above will allow a determination of the economic feasibility using presently grown crops and presently known techniques. However, sufficiently little information has been recorded about such systems that there may be many techniques for utilizing large doses of runoff water effectively. The following steps are suggested for gathering practical information.

1. One man with training equivalent to at least a B.Sc. in Agriculture should be assigned to become the

provincial sailaba expert. He should be provided with a jeep, a driver and two field assistants who can help him install and monitor sailaba systems in cooperation with farmers. He should take the On-Farm Water Management training available in one of the other provinces.

2. One farm tractor, driver, scraper, planer, cultivator, sheeps foot packer, surveyor's level and rod should also be assigned to the "Sailaba expert."
3. Water management advisers from the Colorado State University team and the S.C.S. team should be requested for the equivalent of two months each year for 5 years.
4. A general work plan should be drawn up, but the "Sailaba Expert," his supervisers and his advisers, involving installation of designed sailaba basins with cooperating farmers.
5. Advertisement of the program should be through agriculture extension personnel in the relevant district. Farmers would make application for the program on a first come, first served basis. The government would supply all equipment, fuel, materials and design work. The farmer would provide his land and all needed labor and would agree to accept guidance in cropping schedules and assist in monitoring the system for a period of 5 years.
6. The most promising low cost and high performance designs for overflows and other structures would be incorporated in the system designs.

Standard crops such as wheat, maize, sorghum and melons would be planted in the basins. Additional crops showing potential for deep rooting would be tested for rooting depth and production. In situations where the basins are filling every year, cultural practices to allow growth of high value long term crops such as apples, almonds, grapes, etc., should be evaluated.

Possibilities for extracting water from greater depths by using special cultural techniques should be tested. For instance in a situation where one big runoff event is expected per year which could wet 8 feet of soil with 24 inches of water, vine crops such as melons, tomatoes and grapes could be transplanted as young plants with their roots at the bottom of a four-foot deep auger hole and with a single vine with a few leaves on the tip protruding from the soil. Production of the plants on the applied water supply would be monitored and compared with standard planting techniques.

7. Areas of watershed should be estimated and rain gauges installed to monitor rainfall. Farmers should be asked to estimate when the rain started and stopped and to record or mark the level of water in the gauge following the rain. They should also be asked to record or mark the level of water in each sailaba basin immediately following the rain and at 12 hour

intervals until the water has all been absorbed by the soil. He should also be asked to weigh all produce removed from these sailaba basins. Local extension field assistants would be asked to assist as needed in the early stages of monitoring these systems, and possibly during harvest to increase the probability of obtaining measures of the yields.

8. Annual work plans would be prepared by the "expert", his advisers, his supervisers and such cooperating farmers as circumstances suggest.

9. Annual reports and "Guidelines" for sailaba water management would be prepared. The latter item will be written with assistance from his advisers and will be prepared for use by the Irrigation and Agriculture Departments.

10. If possible, this program would be funded as part of "Barani Lands Water Management Project" funded by the Agricultural Research Council with USAID backing. This proposal, presently under consideration, would follow up some of the lines of research described in the discussion paper titled "Potentials for increasing crop yields through improved water management in barani lands of Pakistan," prepared at the request of the Director General of the Agricultural Research Council by W. D. Kemper, Shahid Ahmad and B. M. Khan.

Additional work which might be done in Baluchistan under this study would be to evaluate increased runoff from land caused by compaction as a means for gaining more water when watershed sizes are limited.